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RECENT DEVELOPMENTS IN ELECTRICAL UNITS

BY

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Recent Developments in Electrical Units

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Actions have been taken recently by international bodies toward adoption in 1940 of new absolute unit standards for electrical quantities. A brief outline of the development of international standards and of the significance of the change are given in this article by an outstanding authority long active in this field.

IT IS proposed here to present a summary of the actions taken by the International Electrotechnical Commission advisory committee number 24 on electric and magnetic magnitudes and units (EMMU), June 23–24, 1938, in the plenary meeting at Torquay, Devonshire, England, with such brief historical outline as may enable electrical engineers who have not attempted to keep in touch with the development of the meter-kilogram-second (mks*) system to follow the most recent decisions.

The International Electrotechnical Comission

The IEC was brought into existence by a motion from the chamber of delegates to the International Electrical Congress of St. Louis in September 1904.[1] The work of organizing the IEC was promptly taken up by Colonel R. E. Crompton, who now in his ninety-fourth year is still living in England. It must be a great satisfaction to him to see how internationally important his IEC has become during his lifetime. The general secretary since the first meeting for organization held in London in 1906, has been C. LeMaistre, London, to whose invaluable services the IEC has been so greatly indebted. The present international president of the IEC is Professor L. Lombardi of Rome who not only was a member of the committee of the St. Louis congress which recommended the formation of the IEC but has remained an active supporter ever since and has done much notable work in preparing an international IEC vocabulary of some 2,000 technical terms, the first edition of which was accepted at Torquay.[2]

Twenty-seven nations now are affiliated with the work of the IEC, each nation maintaining a local national committee with its own officers. Plenary meetings of the IEC have been held in a number of cities of the world. The most recent, the ninth, was held at Torquay in June 1938. At these plenary meetings the international decisions on electrotechnical matters are formulated and adopted.

The work of the IEC is divided among some 25 advisory committees with their secretariats situated in different countries. The advisory committees agree to hold their own meetings about twice a year between plenary meetings; numerous such meetings have been held. A very large amount of international electrotechnical standardization has been satisfactorily effected by the IEC during its 33 years of existence, to the benefit of all countries. Even a brief summary of these actions would be too long to present at this time. Its actions are substantially unanimous. Those questions on which opinion appears to be divided are set aside until substantial unanimity can be secured. The IEC authorizes the convocation of International Electrical Congresses, the last of which, the eighth, was held at Paris in 1932 to mark the semicentennial anniversary of the first Congrès International des Electriciens in 1881. All the official actions of the IEC are published in two languages, English and French. Any third official language might be devastating in its effect as even the maintenance of two languages has been found to be very onerous to the institution.

Brief Historical Outline of the Giorgi MKS System

Professor G. Giorgi of Rome conceived and published the mks system in 1901. In 1904 he presented a paper on the subject to the International Electrical Congress of St. Louis.[8] He showed that by taking the *meter* instead of the *centimeter* as the unit of length, and the *kilogram* instead of the *gram* as the unit of mass, retaining the mean solar *second* as the unit of time, with an appropriate fourth fundamental unit, the centimeter-gram-second (cgs) system became converted into an absolute system including all of the practical electrical units thus far adopted, in simple one to one relationship, thereby eliminating the numerical factors 10^7, 10^8, 10^9, etc., which connect those practical units with their basic cgs units, thus simplifying the work of the electrical-engineering student. Thus a *kilogram* mass ($m = 1$),

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The author is indebted to the following persons for valuable suggestions and amendments: Doctor C. H. Sharp, president of the United States National Committee of the International Electrotechnical Commission; Doctor L. J. Briggs, director of the National Bureau of Standards, and members of his staff; C. LeMaistre, general secretary of the IEC; Professor L. Lombardi, president of the IEC; and M. A. Pérard, director of the International Bureau of Weights and Measures at Sèvres.

*In international usage, italic capital letters (*C.G.S.*, *M.K.S.*) are the accepted abbreviations for systems of units. This article has been modified to conform to American standard representations.

1. For all numbered references, see list at end of paper.

moving freely at a velocity ($v = 1$) of one *meter per second* relatively to its environment, possesses a kinetic energy, $mv^2/2$, of $^1/_2$ *joule* for the mks system just as a mass of one *gram* with the velocity of one *centimeter per second* has corresponding kinetic energy, $mv^2/2$, of $^1/_2$ *erg* for the cgs system.

The advantages of the mks system were recognized by the EMMU committee meeting of the IEC in 1930. At a meeting of the United States Committee of the International Physical Union (IPU) at Chicago in 1933, a resolution was passed favoring the adoption of the mks system. Later in 1933 the EMMU committee met at Paris and endorsed the Chicago IPU resolution referring the question of the mks system to the consideration of the various national committees of the IEC. In 1935 the IEC plenary meeting at Scheveningen-Brussels adopted the mks system without settling the question of "rationalization," appealing to the IPU and to the International Committee of Weights and Measures for an opinion as to the best fourth basic unit for the system.

IEC Plenary Meeting at Torquay in Relation to EMMU

Advisory Committee Number 24 of the IEC convened at Torquay on June 23–24, 1938. Torquay is hallowed to all electrotechnicians as being the residence for many years of Oliver Heaviside, the great master of applied mathematics. Fourteen countries were represented by delegates to the total number of 29 (Argentina, Australia, Czechoslovakia, Ecuador, France, Germany, Great Britain, Holland, Italy, Norway, Poland, Roumania, Switzerland, and the United States). The sessions were presided over by Doctor Clayton H. Sharp, president of the United States National Committee, the secretariat for the advisory committee number 24 being situated in the United States.

The following actions are quoted from the original minutes of the meetings:

1. The minutes of the preceding meeting of the committee held at Scheveningen-Brussels in 1935 were read and approved. At that meeting the IEC formally adopted the Giorgi MKS system without opposition, after the subject had been thoroughly discussed by the various national committees for several years.

2. The question of the rationalization of the MKS system was laid on the table and deferred for future consideration. There has been much difference of opinion in all countries as to whether the Giorgi MKS system should be rationalized or unrationalized. The decision turns upon the question whether the MKS unit of magnetomotive force should be the *ampere-turn* or the *ampere-turn*/4π. The same question had been purposely left unsettled at the Scheveningen-Brussels meeting of 1935 for fear of producing dissension detrimental to the general acceptance of the system if a vote were taken upon the matter at that time. It is hoped that in the course of a few years electrotechnical opinion may become crystallized upon the matter, permitting a nearly unanimous vote to be secured.

3. The committee, noting the concordant replies of Comité Consultatif d'Electricité and of the Symbols, Units, and Nomenclature (SUN) Committee of the International Union of Pure and Applied Physics as to the choice of a fourth unit in the Giorgi MKS system, agreed to recommend, as the connecting link between the electrical and mechanical units, the permeability of free space with the value of $\mu_0 = 10^{-7}$ in the unrationalized system or $\mu_0 = 4\pi \times 10^{-7}$ in the rationalized system. The committee recognizes that any one of the following practical units, *ohm, ampere, volt, henry, farad, coulomb, weber* already in use may equally serve as the fourth fundamental unit, because it is possible to derive each unit and its dimensions from any four others mutually independent. (Note: The necessity for high accuracy has usually led the national laboratories to base the realization of the absolute units on determinations of the absolute *ohm* and the absolute *ampere*. For purposes of technical measurements, however, the practical standards are generally those of resistance and electromotive force as they have the advantages of portability, simplicity, and accuracy in use. Standards of these two quantities are maintained by the Bureau International des Poids et Mesures at Sèvres.)

4. The committee voted upon the question, appearing in the agenda, of adopting the name *newton* for the unit of force of the Giorgi MKS system, (10^5 *dynes* in the CGS system or roughly the weight of one *hectogram* of matter, or more nearly 102 grams, at sea level). The vote was ten to three in favor of the motion, with one country abstaining, subject to confirmation by the various national committees under the six-months rule. The ten accepting countries were Australia, Czechoslovakia, Ecuador, France, Great Britain, Holland, Poland, Roumania, Switzerland, and the United States.

5. It was voted that the name of the system should be the Giorgi (MKS) system and Professor Giorgi, who was present as an Italian delegate, was requested to prepare a further memorandum explanatory of the use of his system.

The preceding resolutions were forwarded to the committee of action of the IEC and formally accepted in plenary meeting. For further particulars the reader is referred to the forthcoming official minutes of the IEC Torquay meeting as appearing in the French and English texts.[4]

International Committee of Weights and Measures at Sèvres

By an amendment to the Convention of the Meter formulated at the General Conference on Weights and Measures of 1921, authority over electrical units was assigned to that conference and its subordinate organizations, the International Committee and International Bureau of Weights and Measures. The Weights and Measures Conference acting on reports from the various national physical laboratories decided that the specifications for the international standard *ohm, volt, ampere,* etc., set up by the Chicago congress of 1893 and elaborated by the London conference of 1908,[5] had not met international requirements to the degree of precision desired. It directed the International Committee of Weights and Measures to set aside the "international" standard series and specifications in favor of new standards based upon new absolute measurements of the absolute practical units embodied in wire resistance coils of improved construction and improved standard Weston cells, made by the national physical laboratories. Copies of these new "absolute" standards are to be deposited at Sèvres so as to permit of ready intercomparison. It had been found that the "international" *ohm* and "international" *volt* prepared in the national laboratories of any one country according to the specifications of 1893 and 1908 differed slightly and were also subject to small but distinct changes with time so that the "international" *ohm* of one country

might differ from the "international" *ohm* of other countries by amounts considerably in excess of the observational errors of comparison.[6,7] The countries taking part in the production of the standards of the absolute practical units were France, Germany, Great Britain, Japan, Union of Soviet Socialist Republics, and the United States.

The International Conference of Weights and Measures is required by treaty to meet in Paris, ordinarily at regular intervals of six years, so that its next meeting is projected for 1939. The International Committee on Weights and Measures, the president of which is the well-known scientist Professor V. Volterra of Rome, meets every two years at the International Bureau of Weights and Measures at Sèvres. The Bureau under the direction of M. A. Pérard maintains the prototype standards of length and mass—the international *meter* and international *kilogram*. It is ultimately proposed to maintain also at the Bureau standards of the practical absolute electrical units based upon the values of the standards from the national laboratories as well as international standards in photometry and thermometry.

In 1935 the International Committee of Weights and Measures with the aid of its Comité Consultatif d'Electricité issued a table of probable ratios between the "international" and the corresponding "absolute" units, to four decimal places (see table I).[8]

It was recommended by the international committee that the new absolute units at Sèvres should go into effect on January 1, 1940, also that the pre-existing standards in various countries should not be altered but that the new standards after January 1, 1940, should conform to the finally established mean ratios. At its meeting in 1937 the international committee announced the revised provisional ratios carried to five decimal places, obtained up to that date from the national physical laboratories, as follows:[9]

one international mean ohm = 1.00048 absolute ohm
one international mean volt = 1.00036 absolute volt

From these it may be inferred that the mean international ampere is 0.99988 absolute ampere and similarly the ratios for the other electrical standards are derivable. Not all of the co-operating national laboratories had completed their comparisons at the date of the 1937 meeting so that the above ratios to five decimal places are not yet final.

It has been supposed by some that the mks system could not be employed until the standards fixed upon at Sèvres had been put into effect in 1940, but it is evident that the actions to be taken by the International Committee of Weights and Measures do not affect the theory or application of the Giorgi mks system but only the international standards of the absolute units to be maintained at Sèvres. The mks system is now ready for use by students and writers, after they have decided whether in electromagnetics their units shall be rationalized or unrationalized. A corresponding choice, in this respect, has also to be made by those who use the cgs units. Textbooks are in course of publication for illustrating the use of the mks system to students and articles upon the elementary application of the system will no doubt appear in technical journals from time to time in the near future.

The original British Association for the Advancement of Science (BA) *ohm* adopted provisionally at the Paris congress of 1881 represented the resistance under standard specifications of a uniform column of mercury approximately 104.8 centimeters in length. Following the commission's report of 1884 the BA *ohm* was replaced by a new ohm called the *legal ohm* of approximately 106.0 centimeters, an increase of more than one per cent. By the action of the Chicago congress of 1893 the *legal ohm* was replaced by the *international ohm* of approximately 106.3 centimeters, representing an increase of about one-quarter of one per cent. Under direction of the International Conference of Weights and Measures the *absolute practical ohm* in the form of standard coils is expected to correspond approximately to 106.25 centimeters, a reduction of about 0.05 per cent or in the ratio 1/1.0005. The corrections to be made in the other electrical standards are all smaller than those in the standard *ohm* with the exception of the *farad* and *henry* whose corrections are the same as for the *ohm*.

Table I

International	Absolute
Ampere	0.999 9
Coulomb	0.999 9
Ohm	1.000 5
Volt	1.000 4
Henry	1.000 5
Farad	0.999 5
Weber	1.000 4
Watt	1.000 3
Joule	1.000 3

The readjustment of the electrical units effected in 1885 and 1894 did not give rise to any serious amount of confusion or misunderstanding. The corrections due to be made in 1940 will be insignificant from the standpoint of ordinary electrotechnics but in electrophysics will need to be taken into account by numerical coefficients when accurate measurements are required.

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